Testimony for the House Science Committee, Subcommittee on Space and Aeronautics, 2002 Oct. 3

Brian G. Marsden, Director, Minor Planet Center

Accurate measurements of the positions of asteroids and comets, including known and candidate NEOs, are received by the Minor Planet Center (located at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts) many times a day in e-mail messages from up to perhaps 150 observatories (both professional and amateur) around the world. Although something like half a million observations are received every month, it is important to appreciate that NEOs comprise only between 0.1 and 1 percent of the observations of asteroids as a whole, almost all of which are confined at quite safe distances from the earth in what is termed the "main belt" between the orbits of Mars and Jupiter. Particularly when they are near the earth, NEOs are usually recognizable by the fact that their apparent motions across the sky are greater than those of the main-belt asteroids, although when they are farther away (and, of course, fainter), the sky motions of NEOs and main-belt asteroids can be comparable and therefore not easily distinguishable.

The principal programs in the world for surveys for new NEOs are the ones bearing the acronyms LINEAR and NEAT (programs based in Massachusetts and California, respectively, that are largely funded by NASA but use USAF telescopes in New Mexico and Hawaii, the latter also in conjunction with a non-USAF telescope on Palomar Mountain in California), as well as three programs (also largely funded by NASA) using telescopes in Arizona. Data from these programs represent well over 80 percent of the observations received at the Minor Planet Center, where they generally arrive during the afternoon after the images were exposed. On its most productive nights LINEAR might record as many as 15,000 different objects, in which case the data may not reach the Minor Planet Center until evening. With typically from three to five observations of each object made over the course of 30–60 minutes the objects with the more unusual apparent motions can readily be picked out (usually by the observers themeselves), and calculations are then made at the Minor Planet Center, first to check whether these objects are already known, and if not known, to identify those that seem most likely to be NEOs. Within 15–30 minutes of the receipt of the data, the Minor Planet Center is then able to place predictions of the likely sky positions (for the next day or so) of the best NEO candidates in the WWW on what is known as "The NEO Confirmation Page". Observers around the world regularly check this webpage. Since afternoon in Massachusetts is already evening in Europe, it is sometimes then a matter of less than an hour before the Minor Planet Center receives confirmatory observations of the NEOs from observatories in Europe, at which point the orbit calculation can be refined and an improved prediction posted on the webpage well before it is night-time in the U.S. and further observations can be made from there. Those new U.S. observations will frequently include both further deliberate observations of the candidate NEOs and more accidental observations of the same objects by the survey programs that will come to light when the Minor Planet Center examines the next night's data from those programs.

With three separate groups of observations (the discovery data from LINEAR or NEAT, then ideally confirmatory data from Europe and follow-up data from North America the night after the discovery), it is usually possible to derive a moderately good estimate of the real orbit of an NEO, and at this point a unique designation is given to the object (the year, two letters and sometimes additional numerals), and all the relevant information (including appropriate credit to the observers) is collected and published on an official *Minor Planet Electronic Circular*, which is both distributed by e-mail and made accessible on the

WWW. At the same time, the prediction on The NEO Confirmation Page is removed, in order to make way for further entries. At any given time, there might be as many as 20 or 30 NEO candidates awaiting confirmation, but by pruning the list there is more chance that the follow-up observers will concentrate on the objects most in need of attention. Of course, further refinement of the NEO orbits is still very necessary using observations made during the weeks (and also the years) after discovery, and the Minor Planet Center routinely disseminates this additional information in a "Daily Orbit Update" Electronic Circular that is prepared automatically in the wee hours of the morning from the data received the previous day.

The current scientific staff of the Minor Planet Center consists of one Federal Employee (Smithsonian Institution), one person funded from a contract with NASA via the Jet Propulsion Laboratory and one person paid from subcriptions to the Minor Planet Center's publications. Allowing for absences, this is technically insuffiecnt for the 16/7 operation the Center tries to maintain. There is clearly a need for at least two more employees, including a systems engineer who would be charged with maintaining the Center's cluster of computers, which are purchased from gifts made to the Smithsonian by a private foundation in California.

As a final step in the dissemination process, it should be noted that calculations are now regularly performed by other groups, notably at NASA's Jet Propulsion Laboratory, of any remote possibilities that specific NEOs could collide with the earth during the next century. Such calculations are fairly extensive but are quite automatic and entirely based on the observations organized and distributed by the Minor Planet Center. They are also routinely updated using the daily updates of NEO observations. Of course, it is almost always to be expected that, as further data are acquired, the impact possibilities completely disappear. That is, they will disappear unless the earth is actually going to experience an impact—a point the dinosaurs 65 million years ago were unable to appreciate.

Most of the deliberate confirmatory and deliberate follow-up observations of NEOs, particularly those obtained in the U.S., are made by amateur astronomers. There are perhaps ten U.S. amateur groups and individuals (notably in Arizona, California, Kansas, New Mexico, Oregon, Tennessee and Wisconsin) who can be depended upon to make such observations, reliably and systematically. Although amateurs do still regularly discover main-belt asteroids (despite the dominance of the professional surveys), it is really quite rare for them to discover NEOs, but there have been NEO discoveries by amateurs in Arizona, and even Massachusetts, during the past two or three years. Amateurs tend to do better at discovering comets—some of which are technically NEOs—because these usually have a distinctive appearance and can often be found in the parts of the sky that are closer to the sun than are covered by the professional surveys. The Edgar Wilson Award for comet discoveries has therefore actually been made to between two and seven amateur astronomers each year. While the part of Pete Conrad Award for NEO discoveries will also be of some encouragement to recipients, the part awarded for follow-up observations should actually be more so. Perhaps the principal encouragement to amateurs nowadays is to make it possible for them to have ready access to the equipment they need to carry out their work. Government and private grants that have provided amateurs with electronic detectors during the past few years have been particularly effective. Of course, the Conrad and Wilson Awards could provide the same end result, but there is no guarantee. It should also be noted that there are better prospects for amateur discoveries in the southern hemisphere, because of the absence of professional surveys there.

For more than a half-century after its inception in 1947, the Minor Planet Center functioned with just two scientific staff. By the time a third member was added in May 2000 the number of observations in its files had grown to 4.5 million (effectively from zero) and the number of objects with orbit determinations to 80,000—of which the 15,000 of guaranteed quality (i.e., the asteroids that have been given sequential numbers, and in some cases, names) represented a tenfold increase over the situation in 1947. The number of known NEOs in May 2000 was under 1000, with some 400 of them more than 1 km across. Now there are more than 15 million observations and very nearly 200,000 objects with orbit determinations—now almost 50,000 of these being numbered asteroids. There are now more than 2000 NEOs, of which some 640 are larger than 1 km. The Minor Planet Center's staff has been able to keep up with the influx, but only because of its extreme dedication. As already noted, a modest further increase in the size of the staff would be desirable—and it will be essential if the Center is to keep up with the exponential increase in data for much longer. Computing capabilities at the Minor Planet Center are very good, with new machines added from time to time, and since one staff member is particularly involved with upgrading the software, some augmentation of the staff would also allow that member to concentrate more on this important task.

Although the official NASA mandate is to concentrate on NEOs that are 1 km across or larger, there are already data on many smaller NEOs in the files. There are some 1800 NEOs down to 200–300 meters (this number increasing by around 400 annually), out of perhaps 40,000 that must exist. Even with the present observational and computational capabilities, the inventory of known objects could be a substantial fraction of the estimated total after several more decades (particularly if one also considers redefining NEOs to include only those objects that pass somewhat closer to the sun than the present limit of some 120 million miles, for asteroids at that minimum distance cannot possibly be a significant threat to the earth, at 91–95 million miles, for millions of years into the future). Making use of larger telescopes could allow 200-meter NEOs to be sampled to a completeness level approaching 90 percent after just a decade or two. (One worry about some of the proposed telescopes is that they are really designed for surveys of objects outside the solar system, and therefore only one image of a particular field would be obtained on a given night. As noted at the beginning of this testimony, the apparent motion of an object over an hour or so is essential for recognizing NEOs. It is also essential for linking data on a particular object from one night to another.) Given the expected increases in computing capabilities during that time, the Minor Planet Center could keep up with this (as it has clearly done before), again provided that there are sufficient staff members. It should be remembered that NEO observation, with the need for confirmation and follow-up, is necessarily an international activity, for the simple reason that it is not possible to observe the whole sky from the U.S., and it is not possible to observe the reachable sky at all times. The Minor Planet Center, with its international connections, is well-equipped to attend to this point.

If it is decided that it would ultimately be desirable to extend the NEO searches down to a size limit of, say, 50 meters, with perhaps a million objects to find, the whole perspective does change quite significantly, and it would clearly then become efficient to make the searches from space-based telescopes. Data-management requirements would also become much more intensive, with a clear need for round-the-clock attention. While this might be the ultimate goal, the more obvious immediate step is to go down to the 200–300-meter level, as was discussed in the comprehensive Task Force Report on NEOs to the U.K. government in 2000. This would be a logical and effective transition that could be accomplished quite rapidly, and the increased data-management requirements could be reasonably addressed, as discussed in the previous paragraph.

Dr. Brian G. Marsden is an astronomer at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, and specializes in celestial mechanics and astrometry, with particular application to the study of comets, asteroids and natural satellites. He was born in Cambridge, England, and his undergraduate education was at Oxford University. He received his Ph.D. degree from Yale University, his dissertation being concerned with the orbits of the Galilean satellites of Jupiter. He has examined in particular the nongravitational forces that affect the motions of comets, has extensively studied the Kreutz group of sungrazing comets and is an authority on procedures for deriving useful orbital information from minimal information—something that is proving very applicable to the numerous transneptunian objects discovered in recent years. He has successfully predicted the return of several lost comets and asteroids, notably the 1992 return of Comet Swift-Tuttle, which has the longest period of any comet ever successfully predicted. In 2002 he recognized another group of now more than a dozen near-sun comets that is termed the Marsden Group. He is the author of the standard *Catalogue of Cometary Orbits*, fourteen editions of which have been published since 1972. He was director of the International Astronomical Union's Central Bureau for Astronomical Telegrams from 1968 to 2000, and in this capacity has been responsible for the timely dissemination of information about transient astronomical objects and events; since 1978 he has also directed the IAU's Minor Planet Center, which issues various printed and electronic publications, including monthly batches of *Minor Planet Circulars* with positional observations, orbital elements and related information about comets and asteroids. From 1987 to 2002 he was Associate Director for Planetary Sciences at the Harvard-Smithsonian Center for Astrophysics. He has also served as Chairman of the American Astronomical Society's Division on Dynamical Astronomy (1976–1978) and as President of the IAU's Commission on the Positions and Motions of Minor Planets, Comets and Satellites (1976–1979); he was on the Board of Directors of The Spaceguard Foundation (1996–2002), serving in particular as Vice President during 1998–2002; and he is currently President of the IAU's Commission on Astronomical Telegrams. In 1974 the minor planet (1877) was named in his honor. Among his several other honors are the Goodacre Medal of the British Astronomical Association in 1979, the University of Arizona's Van Biesbroeck Award for services to astronomy in 1989, the Camus-Waitz Medal of the Société Astronomique de France in 1993, the AAS Brouwer Award for research in dynamical astronomy in 1995 and the Lacchini Prize of the Unione Astrofili Italiani in 2001.